Analyze of Verbs in Requirements with Natural Language Processing to Enhance Comprehension

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Abstract. Purpose: There can be some ambiguity when describing requirements using natural language. One of the critical parts of the requirement syntax is using verbs to express the action of the requirement. Therefore, it is essential to explore how verbs can be used in requirements to convey their intended meaning accurately. **Problem:** This study aims to investigate the action entity of ISO/IEC/IEEE-29148:2018 requirement syntax and establish a connection between the verbs used to express requirements. **Methods:** Using Spacy, a natural language processing library, to analyze 955 aerospace requirements from 2017-2022. Verbs are extracted and compared to the ISO/IEC/IEEE-29148:2018 action part of the requirement syntax. **Results:** The verbs used in a requirement express the desired action. In the requirements studied, it was observed that a particular verb was used more frequently than others. However, it is essential not to overuse a single verb to avoid confusion and ensure a better understanding of the requirement. Choosing the correct verb to describe the requirement can avoid misunderstandings in interpretation. **Conclusion:** This research aims to provide insight into the usage of verbs in requirements. However, additional research is necessary to determine how the verb functions with other grammatical elements within the requirements.

Keywords: Requirements · Natural Language Processing · IEEE29148.

1 Introduction

Natural language is frequently used in software development to express requirements [9, 16]. It is important to remember that natural language can often be ambiguous, meaning that a single phrase or sentence can have multiple interpretations or meanings [4, 7]. The ambiguity of words and sentences is a well-known and widely studied problem that results in different interpretations of a text [11].

Drawing a clear line between a written requirement and natural language that describes a system typically depends on the expertise and intuition of professionals in the field. However, it is challenging to identify the linguistic properties of a requirement that distinguishes it from similar sentences within a design document [21].

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The standardization of how to represent the requirements can be beneficial in a large set of requirements once it improves the understanding in the long term; for instance, the ISO/IEC/IEEE-29148 [10] presents a requirement syntax that describes the requirement when using natural language, the requirement syntax consists in five entities present the requirement sentence (see Figure 1).

[Condition] [Subject] [Action] [Object] [Constraint of Action]

EXAMPLE: When signal x is received **[Condition]**, the system **[Subject]** shall set **[Action]** the signal x received bit **[Object]** within 2 seconds **[Constraint of Action].**

Or

[Condition] [Subject] [Action] [Object] [Constraint of Action]

EXAMPLE: At sea state 1 **[Condition]**, the Radar System **[Subject]** shall detect **[Action]** targets **[Object]** at ranges out to 100 nautical miles **[Constraint of Action].**

Or

[Subject] [Action] [Constraint of Action]

EXAMPLE: The Invoice System **[Subject]** shall display pending customer invoices **[Action]** in ascending order of invoice due date **[Constraint of Action].**

Fig. 1. Natural language requirement syntax (ISO/IEC/IEEE-29148, 2018).

The requirements for natural language processing are primarily derived from the various linguistic constructs and their corresponding meanings embedded within the language. These constructs include the grammatical rules, vocabulary, and syntax that form the foundation of any language, and it is through these constructs that we are able to derive the intended meaning of a given text or statement [6].

The objective is to simplify the sentences and, thus, reduce their complexity. leaving the margin for interpretation as minimal as possible [20]. Consequently, improving the quality of the requirements regarding cohesion and consistency [4]. From the five entities presented in Figure 1, the action entity is the core of the sentence once the verb relies on that section, and the verb is a word that is used to refer to actions (what things do) and states of being (how things are).

Multiple verbs can be used to describe a requirement, and some of these verbs can work as synonyms. However, the lack of standardization can lead to misunderstanding, once each person that reads the requirement can interpret it as their wishes. Thus, documents were analyzed to investigate the most used verbs to establish verb usage standardization requirements. Requirements from the aerospace sector were the choice once it deals with a critical safety environment [19], and the caution in the specification is inherent.

The SpaCy library was chosen to analyze the verbs present in the selected requirements. SpaCy is an open-source Python library explicitly designed for Natural Language Processing (NLP) tasks. It provides a robust set of features for processing and analyzing text. A valuable resource for text processing in

Python is provided by spaCy, whether information is being extracted, context is being understood, or custom NLP systems are being built.

The SpaCy is used to perform Part-of-speech tagging in the requirement by identifying the grammatical role of each word in a sentence; dependency parsing: Analyzing the grammatical structure and relationships between words (see Figure 2) and Word vectors and similarity: Representing words as vectors and measuring their similarity.

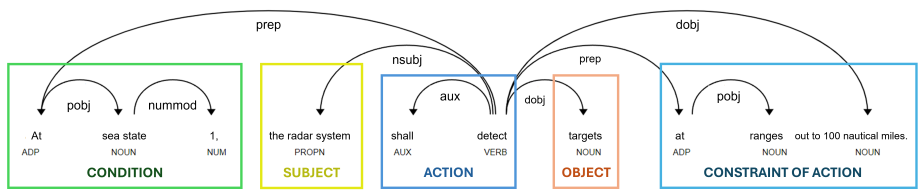

Fig. 2. Visual representation provided by the Spacy from the requirement shown in Figure 1.

An analysis can be performed once the requirement pattern is established (ISO/IEC/IEEE-29148 syntax), and SpaCy provides a way to investigate the grammatical elements within the requirements. In the results section, it is observed that several requirements have more than one verb and that requirements with the same action are written with different verbs (in the same document). When examined by SpaCy, these "similar" verbs return no similarity, and an analysis of testing with other verbs showed better similarity.

It is important to note that writing requirements are more than simply putting words on paper [19]. The choice of language and how the words are put together significantly impact the comprehensibility of the requirements. Therefore, this research aims to compare the current written requirements to identify areas that can be improved for enhanced comprehension.

2 Methods

2.1 Sample Preparation

To perform the requirements verb analysis, requirements documents from the space sector were collected over the web. Eight documents were chosen:

1. GOES-R Series Mission Requirements Document (MRD) from NASA (2022) [14];
2. Geostationary Operational Environmental Satellite (GOES) GOES-R Series Level I Requirements (LIRD) from NASA (2020) [13];
3. Next Generation Gravity Mission as a Mass-change And Geosciences International Constellation (MAGIC) Mission Requirements Document from ESA/NASA (2020) [8];

4. Gateway System Requirements from NASA (2019) [1];
5. ISS Safety Requirements Document (2019) [3];
6. International Space Power System Interoperability Standards (ISPSIS) from NASA (2022) [18];
7. Copernicus CO2 Monitoring Mission Requirements Document from ESA (2019) [2]; and
8. Crewed Space Vehicle Battery Safety Requirements Revision D from NASA (2017) [17].

A total of 955 requirements were captured manually and stored in an Excel spreadsheet that contains the following columns: **ID**: increase sequentially inside the spreadsheet and serve to identify and refer to a specific requirement; **Doc. ID**: stores the identification of the requirement found inside the document; **Type Req. Doc.**: record the type of requirement according to the document, e.g., maintenance, security, external interface requirements, etc.; **Requirement**: expresses the requirement found in the document. Figure 3 shows the arrangement of the columns in the Excel spreadsheet.

ID	Doc. ID	Type Req. Doc.	Requirement
1	MRD36	System Life	The GOES-R System shall provide an individual satellite lifetime of 5 years of storage and 10 years of operations for each satellite in the series.
2	MRD44	Orbits	The GOES-R System shall position satellites at 75 degrees West longitude and 137 degrees West longitude at geosynchronous altitude during nominal
3	MRD2081	Orbits	The GOES-R System shall operate satellites at 89.5 degrees West longitude at geosynchronous altitude for initial satellite checkout.

Fig. 3. Excel columns arrangement to store the requirements in searched documents.

2.2 Localizing and Storing the Verbs within The Requirements

In conjunction with a natural language processing (NLP) library called Spacy, the Python language was utilized to analyze each requirement. The Spacy loads the en_core_web_lg model, which provides word vectors and linguistic annotations.

Each requirement cataloged could have more than one sentence, and the requirement can be present in any sentence. Thus, the spaCy divides the requirement by the number of sentences found. Furthermore, each sentence is separated into tokens.

These tokens have grammatical units that play different roles in a sentence, such as nouns, verbs, adjectives, adverbs, pronouns, and prepositions, and syntactic dependency labels to describe relations between individual tokens like subject or object.

It was observed that the captured requirements might contain several sentences and that the verb may be present in any sentence; however, only verbs connected to the word "shall" were considered. Such constraint encompasses the "shall + verb" and "shall + anything + verb". Although "shall + anything + verb" is not an ISO/IEC/IEEE-29148 recommended pattern, requirements are commonly expressed this way. Thus, verbs that express the action of the requirement could be present.

Other patterns different from the explicit determined were ignored and not computed as a verb indicating the requirement's action. The diagram of the algorithm used to extract the verbs within the requirements is presented in Figure 4.

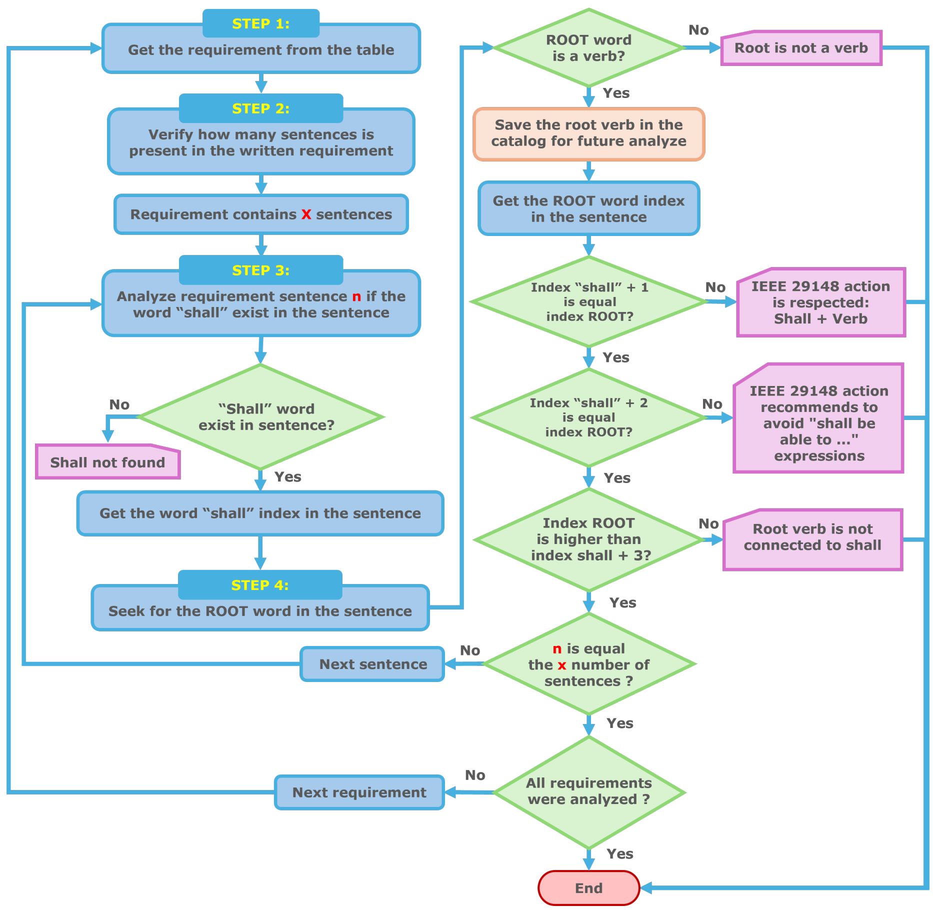

Fig. 4. Research algorithm to discover and store the verbs in conjunction with the sentence flags.

During the analysis of a requirement, it goes through a four-step process. Firstly, the requirement is fetched. In the second step, the requirement is broken down into sentences using the spaCy library. The third step involves searching for the word "shall" in each sentence of the requirement. The word "shall" is the anchor parameter of the search, as per ISO/IEC/IEEE-29148, where the action segment is composed of "Shall" followed by a verb. This approach helps identify and extract the relevant information from the analyzed requirement.

Once the word “shall” has been found, the algorithm searches for the root of the sentence. Every sentence should have just one word with the root dependency relation. For this research, the root in the sentence must also be a verb. The result of the three first steps is shown in Figure 5, taking the requirement ID: 407 as an example. The spaCy tags the root and the verb (see Figure 6).

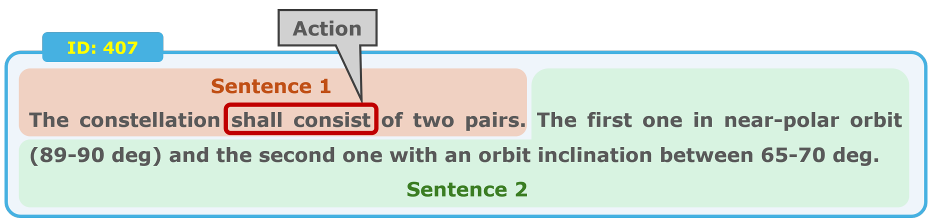

Fig. 5. Requirement ID:407 divided into sentences with the action highlighted.

ID: 407

	idx	text	lemma_	pos_	tag_	dep_	head	morph
0	0	The	the	DET	DT	det	constellation	Definite=Def|PronType=Art
1	4	constell	constellat	NOUN	NN	nsubj	consist	Number=Sing
2	18	shall	shall	AUX	MD	aux	consist	VerbType=Mod
3	24	consist	consist	VERB	VB	ROOT	consist	VerbForm=Inf
4	32	of	of	ADP	IN	prep	consist	
5	35	two	two	NUM	CD	nummod	pairs	NumType=Card
6	39	pairs	pair	NOUN	NNS	pobj	of	Number=Plur
7	44	.	.	PUNCT	.	punct	consist	PunctType=Peri
8	46	The	the	DET	DT	det	one	Definite=Def|PronType=Art

Fig. 6. Requirement ID:407 tags found into first sentences.

Once the shall and the root as a verb was found, in step 4, a series of tests started to determine the relation of these words within the sentence and, consequently, if the relation between them complies with the requirement syntax suggested by ISO/IEC/IEEE-29148 (refer to Figure 1).

Each sentence analyzed delivers flags to be further studied. There are five flags:

1. "shall not found": The word "shall" is not found within the sentence.
2. "Root is not a verb": The root of the sentence is not a verb.
3. "shall plus verb": When the ISO/IEC/IEEE-29148 action is respected and "shall" is followed by the verb that is also the root of the sentence.
4. "'shall be able to ...' must be avoided": When there are a "shall" and a root verb. However, there is a word between them.
5. "Root verb is not connected to shall": When there are a "shall" and a root verb. However, they are not sequentially positioned.

This process is repeated until all the requirements are processed. The results are stored in the same spreadsheet that contains the requirements analyzed. In addition, an analysis was performed to investigate the cataloged requirements regarding the ISO/IEC/IEEE-29148 syntax (refer to Figure 1).

This analysis was made by measuring the difference between the index of the word "shall" and the index of the root of the sentence if this root is also a verb. If the difference is equal to one, the root verb is immediately ahead of the "shall". It matches the requirement of ISO/IEC/IEEE-29148 action entity in syntax; if the difference is two, there is a word between the "shall" and the root verb of the sentence; it is not a recommended ISO/IEC/IEEE-29148 syntax for the action entity.

Other situations violate the action syntax entity of the requirement. For example, the "shall" word can not be found, or the root of the sentence is not a verb. These situations are registered in the spreadsheet on the same line where the requirement is stored to provide further analysis..

3 Results

3.1 Analyze of the Samples

The samples provided by the eight documents represent 955 requirements, which yielded 134 verbs. This represents approximately the verb change in each of the seven requirements written. However, the verbs used to describe the requirements tend to overuse the verb "produce," which corresponds to almost 20% of all requirements analyzed.

3.2 Analyze of the Verbs within the Requirements

The principal analysis was to determine the verbs used, and from the 955 requirements cataloged, 134 verbs were found. Figure 7 presents the distribution of the verbs used to describe the requirements.

Verbs vs. Occurrences in the Analyzed Requirements Documents

Verbs	Qty.	Verbs	Qty.	Verbs	Qty.	Verbs	Qty.	Verbs	Qty.
produce	184	accommodate	5	sample	3	monitor	4	locate	1
provide	110	acquire	5	test	3	calibrate	1	lubricate	1
be	107	collect	5	undergo	3	capture	1	match	1
have	35	communicate	5	center	2	categorize	1	place	1
design	29	co-register	5	conduct	2	certify	1	position	1
meet	26	measure	5	confirm	2	change	1	preclude	1
maintain	24	receive	5	consider	2	clear	1	preserve	1
comply	21	remain	5	consist	2	co-located	1	protrude	1
operate	17	contain	4	cover	2	condition	1	relieve	1
control	15	ensure	4	enable	2	consume	1	remove	1
employ	15	include	4	illuminate	1	curate	1	request	1
implement	15	optimise	4	record	2	decrypt	1	require	1
support	14	overlap	4	recover	2	demonstrate	1	respond	1
protect	12	deliver	4	report	2	derate	1	review	1
make	11	procure	4	restrain	2	discriminate	1	scale	1
use	11	register	4	supply	2	dispose	1	secure	1
develop	10	utilize	4	insulate	2	distribute	1	select	1
limit	10	allow	3	tolerate	2	downlink	1	separate	1
perform	10	apply	3	transition	2	encrypt	1	simulate	1
prevent	10	assess	3	accept	1	equalize	1	track	1
target	10	choose	3	account	1	equip	1	store	1
establish	9	conform	3	address	1	experience	1	tag	1
send	9	detect	3	adhere	1	follow	1	take	1
constrain	8	determine	3	aim	1	function	1	terminate	1
manage	8	evaluate	3	allocate	1	identify	1	transfer	1
exceed	7	isolate	3	archive	1	impede	1	transport	1
incorporate	6	navigate	3	assure	1	ingest	1	validate	1
relay	6	relocate	3	average	1	localize	1		

Fig. 7. Verbs vs Occurrences in the analyzed requirements documents.

At first, it is observed that the verbs "produce", "provide", and "be" were overused. The usage of these verbs was due to the ability to be suitable in several situations describing generic actions. However, some similar requirements use different verbs, including those overused to express the same action. For example, the requirements:

- ID-318: The GOES-R system shall **make** coronal mass ejection L0 data from the GOES-U Compact Coronagraph (CCOR) available to users.
- ID-320: The GOES-R Series shall **provide** user access to all generated environmental data products;

Both requirements are about making/providing data to users. However, when analyzing the similarity between "make" and "provide", SpaCy returns that the words are -0.4949 in similarity. Other synonyms that could be used, Table 1, provide other words and their similarity compared to the word "provide".

From the 955 requirements analyzed, 748 have the "shall" followed by the verb complied with the ISO/IEC/IEEE-29148 requirement syntax action entity

Table 1. Similarity of words according to the SpaCy when compared to the word "provide".

Words	Similarity
deliver	0.7440
implement	0.6971
create	0.6809
develop	0.6787
generate	0.6675
produce	0.6624
supply	0.6241
use	0.6055
connect	0.5592
process	0.4425
display	-0.4360
make	-0.4950

in the first sentence and 3 in the second sentence of the requirements. Figure 8 presents the distribution of the five flags used to describe the sentence. Furthermore, some analyzed requirements did not follow the syntax ISO/IEC/IEEE-29148 proposed. Thus, multiple sentences were inside the requirement, and the action section could be in any of those sentences.

The analysis involved identifying and locating any sentence within the requirement that contained a specific grammatical structure consisting of the word "shall" followed by a verb. The purpose of this exercise was likely to investigate if the requirements were written by ISO/IEC/IEEE-29148 requirement syntax (see Figure 1).

Regarding the requirements, 95.07% addresses the ISO/IEC/IEEE-29148 action entity in the requirement syntax present in the first sentence. The graphic in Figure 8 indicates that most requirements could start with the action in the first sentence of each requirement.

However, the several requirements have more than one sentence, and long requirements can contain several verbs that may induce an interpretation of the requirement with several actions. Figure 9 shows the requirement ID 546, which has presented five verbs in a unique requirement. Moreover, more than one "shall" word was found. Such requirements may present an elevated number of actions, making the requirement challenging to verify.

The object is one of the entities of the ISO/IEC/IEEE-29148 syntax (refer to Figure 1). Grammatically, an object is a part of a sentence that provides meaning to the action of the verb carried out by the subject. Furthermore, some verbs require an object to complete their meaning (transitive verbs), while others do not (intransitive verbs).

An analysis of the verbs collected (see Figure 7) regarding the verb type (transitive, intransitive, or both) indicates that five intransitive verbs (be, comply, remain, consist, and function) were used to describe requirements (see Fig-

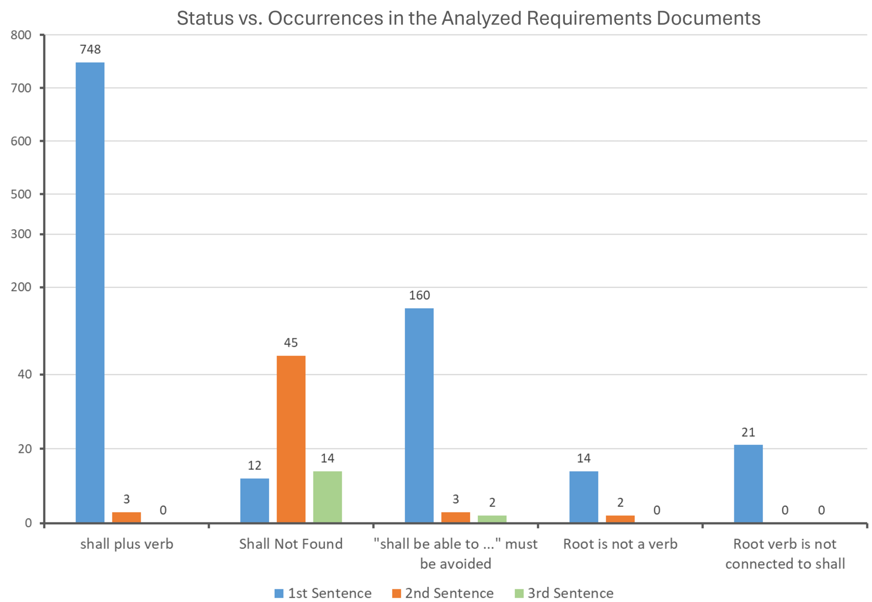

Fig. 8. Status flags vs Occurrences in the Analyzed Requirements Documents.

ure 10). It is noticed that these intransitive verbs are followed by prepositional phrases, which are not objects.

4 Discussion

The eight aerospace requirement documents collected were used to discriminate the verbs used to describe the requirements' actions. Technical specialists typically write the requirements thinking in the technical solution [12]. Using natural language to describe the requirement can generate misinterpretations, and details, such as the verb choice to determine the demanded requirement action, could be neglected [19].

It is important to use consistent verbs in technical documentation to avoid confusion. Different verbs with similar meanings are sometimes used to express the same action. This can make it difficult for the reader to understand the intended meaning. To prevent this, it is recommended to standardize the use of verbs in technical documentation. While following the same structure as a literary work is unnecessary, it is essential to avoid overusing synonyms.

Further research should be conducted to determine the best verbs for each action. When creating requirements documents, it is crucial to use the same verb every time an action is repeated to ensure clarity for the reader [5].

ID: 546

The Gateway shall provide at least single failure tolerance to catastrophic events. a. Catastrophic hazards that cannot be controlled using failure tolerance may be exempted from the failure tolerance requirements with mandatory concurrence from the Technical Authorities and Director, Johnson Space Center (JSC) (for crew risk acceptance). Exemptions from failure tolerance shall be requested in accordance with DSG-RQMT-011, Gateway Hazard Analysis Requirements.

Fig. 9. Requirement ID 546 with several verbs (red rectangle) and multiple "shall + verb" (green rectangle) constructions.

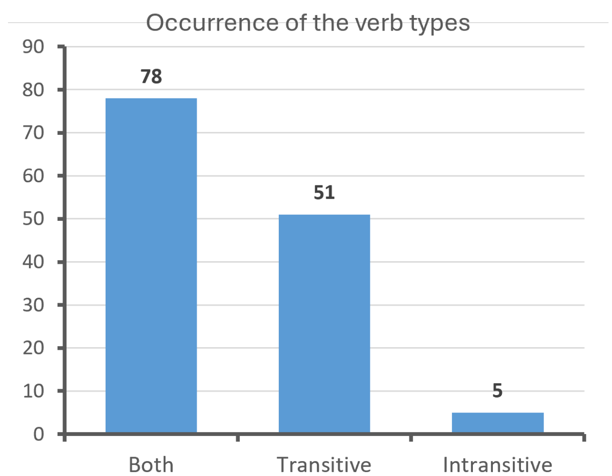

Fig. 10. Occurrences of verbs transitive, intransitive, or both.

Selecting the correct verb for a requirement is only part of the problem. It is also essential to know if the verb is transitive or intransitive. Transitive verbs require a direct object, which means if the requirement is written with a transitive verb, it must have a direct object [9] .

In English, direct objects are typically expressed as noun phrases, which can include articles and adjectives to provide more detail and nuance. When choosing the verb for a requirement, it is essential to select a transitive verb if the requirement needs to express an action. This way, the sentence will not end abruptly without a complement.

Out of the 134 verbs that were cataloged, only five of them were classified as intransitive. This observation is interesting because it suggests intransitive verbs are less commonly used than transitive verbs when describing requirements. This information could be helpful when writing requirements as it could help choose the most appropriate verb for the context.

The analyzed data presented in Figure 8 reveals that several requirements contain multiple sentences and verbs, as evidenced in Figure 9. The presence of multiple verbs within a requirement can cause ambiguity and confusion for the implementer, leading to possible misunderstandings of the requirement's intended action.

To mitigate this challenge, it is advisable to break down long requirements into simpler and short ones [5]. To achieve this, requirements must be expressed in a concise, unique sentence structure, following the lean structure recommended by ISO/IEC/IEEE-29148 (see Figure 1). Applying a short sentence structure leads to test granularity and easier debugging, as the test becomes the smallest part of the project.

5 Conclusion

This research analyzed the verbs used to describe the action inside the requirement. Natural language processing is used to discriminate the grammatical elements from the 955 investigated requirements.

The verb's classification as transitive or intransitive influences the requirement's object that receives the verb action. SpaCy shows that other grammatical elements may interact with the verb and may influence how the elements of the requirements syntax from ISO/IEC/IEEE-29148 relate to each other (see Figure 2).

The choice of the verb implies other grammatical structures of the requirement. How the subject transfers the action to the object and the constraint of the requirement, standardizing the verb usage also can be beneficial in the long term in conjunction with limiting the number to one verb per requirement [5] should be the goal, thus reducing the misunderstanding regarding the requirements by keeping it simple and straightforward.

Using the other SpaCy tools to explore the grammatical formation of the ideal requirement, exploring how the transitive verbs in the action segment interact with the object, constraint of action, and condition in the ISO/IEC/IEEE-29148 requirement syntax.

Once the interaction between the verb and other grammatical elements of the ISO/IEC/IEEE-29148 requirement syntax is established, it can be implemented in a chatbot to assist users in expressing their needs. The chatbot will translate user needs in the format of "As a [user persona], I need/want [user need] so that [user goal/objective]". This way, the chatbot's artificial intelligence will format users' requirements into an ideal format without overloading them with too many word choices, maintaining the standard of the written requirements, and reducing the requirement smells [15].

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